Economic Evaluation of Soybean Fungicide Seed Treatments

By Michael Popp, Ph.D., John Rupe, Ph.D., and Craig Rothrock, Ph.D.

Abstract

The effect of nine different fungicide seed treatments for soybeans were tested from 2004 to 2007 at Keiser, Stuttgart, and Hope, Arkansas. While seedling emergence was effective across all treatments, only three treatments showed statistically significant differences in partial returns, defined as gross revenue minus seed and seed treatment costs. Comparisons of the regret a producer would experience as a result of non-optimal seed treatment suggested that broad spectrum seed treatment could enhance profitability by an average of $32 per acre with similar treatment recommendations across a range of seeding rates, output prices and study conditions.

Introduction

This research examined the cost effectiveness of nine seed treatments for managing seedling diseases in Arkansas soybeans. Seedling diseases are the result of numerous seed and soilborne pathogens. In Arkansas, the most common are *Pythium* spp., *Fusarium* spp. and *Rhizoctonia solani*. While these pathogens have been characterized, no feasible instrument exists to test for their presence at time of planting or their expected impact on yield as a number of additional factors like soil moisture, temperature changes, rainfall, and growing season are uncertain at the time of planting. As a result, the seemingly simple solution of seed treatment to prevent seedling disease at a relatively minor cost has not been adopted to a large extent by producers in Arkansas. To help with this decision, a past study (Poag, et al.) evaluated three promising seed treatments for use in soybean production in Arkansas with a finding that seed treatment was profitable in some cases. This paper is an extension of that work in the sense that a larger range of seed treatments were evaluated.

Seedling diseases can lead to less than optimal plant populations and reduced plant vigor, which in turn can lead to reduced yields and higher weed control cost. Over the period from 2004 to 2007, Arkansas farmers harvested on average three million acres or one-hundred and eight million bushels of soybean annually. Applying an estimated disease-related yield loss of five percent (Koenning) results in annual producer losses of roughly $43 million, assuming a ten-year average soybean price of $7.96 per bushel in 2007 dollars (NASS, 2008 a).

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Also, since seed cost and associated technology fees have made seed-related costs a greater percentage of operating costs (Lambert and Lowenberg-DeBoer), analyses surrounding seeding rates for soybean are important to producers and have been considered in this study. With high commodity prices, there will be even more reason to consider the efficacy of seed treatment given potential yield enhancement and the possibility of avoiding replanting.

In this study, the effects of label-rate applications of nine different seed treatments on seedling emergence and yield were compared to an untreated control (*UNT*). The treatments included i) Fludioxonil (Maxim – *MAX*); ii) Carboxin – Tetramethylthiuram disulfide – Metalaxyl (Stiletto – *ST*); iii) Metalaxyl-Attapulgite clay (AllegianceFL – *AL*); iv) Carboxin + PCNB (Vitavax + PCNB – *VITA*); v) Mefenoxam-Fludioxonil (ApronMaxx RTA-Moly – *AM*); vi) Mefenoxam-Fludioxonil-Axoxystrobin (ApronMaxx-Moly + Dynasty – *AM+*); vii) Mefenoxam-Fludioxonil-Axoxystrobin-Thiamethoxam (ApronMaxx-Moly + Dynasty + Cruiser – *AM++*); viii) Carboxin – Tetramethylthiuram disulfide – Metalaxyl-Imidacloprid (Stiletto + Gaucho – *ST+*); and ix) Trifloxystrobin + Metalaxyl-Attapulgite clay (Trilex + AllegianceFL – *AL+*). This allowed for the assessment of the importance of different pathogens based on the fungicides applied to seed (for example, *AL* targets Pythium spp., *VITA* targets Rhizoctonia solani, *MAX* targets Rhizoctonia solani and Fusarium spp., while *ST*, *AM* and *AM* + are broad spectrum fungicides that target all three groups of organisms). *AM++* and *ST+* have added insecticide control as well.

The specific objectives of this study were to: 1) estimate the relationship between seed treatment and seedling emergence at four weeks after planting (ROS); 2) determine the impact of plant population density (PPD) on yield (Y) across different seed treatment regimens, years, planting months, and locations tested in this study; and 3) present economic sensitivity analysis on the soybean price and seeding rate necessary for economically effective seed treatments.

Materials and Methods

Experimental Description

The data for this study were obtained over four years at three locations: Stuttgart, Arkansas (34° 27' N, 91° 24' W) on Crowley silt loam (fine, smectitic, thermic Albaquultic Hapludalfs), a shallow silt loam soil that has poor water holding capacity; Keiser, Arkansas (35° 39' N, 90° 4' W) on Sharkey silty clay (very fine, smectitic, thermic Chromic Epiaquerts), a deep clayey soil with good water holding capacity; and Hope, Arkansas (35° 22' N, 92° 24' W) on Bowie fine sandy loam (Fine-loamy, siliceous, thermic Plinthic Paleudults), a very deep, very old, stable soil that is moderately slowly permeable. Aside from soil and location differences, other parameters examined included: 1) varying plant densities achieved by changes in row spacing (at a constant 5 seeds per row-ft.) that translated to seeded PPDs ranging from 87,120 per acre with 30" row spacing at Hope in 2007 to 68,779 per with 38" row spacing used at Keiser; 2) artificially altering seed quality to reflect planting of older seed and/or seed that was improperly stored or physically damaged; 3) different seed treatments using manufacturer's labeled rates; and 4) different planting months (April, May, or June). A summary of study conditions is presented in Table 1.

The experimental design was a randomized complete block with seed treatment and seed quality arranged factorially for each set of year, location, and planting month combinations. Plot size was sufficient to control for border effects and harvest of center, two 20-ft. rows for determination of yield adjusted to 13 percent moisture. Seedbed preparation, fertilizer, herbicide, and irrigation regiments were the same across all plots and in accordance with University of Arkansas cooperative extension recommendations (Ashlock).

To avoid problems associated with seasonal or cyclical price effects, a ten-year average soybean price adjusted for inflation was used in this study. A seed price of $0.75 per pound for high quality, glyphosate resistant seed was considered representative of Arkansas conditions for 2007. The varieties, PioneerM9490 and Hornbeck4924, were considered representative of Arkansas soybean producer seed choices available at the time. Further, soybean variety and glyphosate-resistance were not expected to significantly impact seed treatment effects.

Since the cost of different seed treatments was relatively minor compared to seed cost (in turn approximately 15% of operating expenses for soybean production in Arkansas) at a cost of seed treatment in 2007 of $0.04, $0.03, $0.05, $0.01, $0.04, $0.03, and $0.24 per pound of seed for *VITA*, *MAX*, *AL*, *AL+*, all *AM* treatments, *ST* and *ST+*, respectively, the economic impact of the different seed treatments is mainly driven by yield effects with the exception of *ST+* at $0.24 per pound or in excess of $10 per acre at a recommended 45 lb./acre seeding rate. Since yields are expected to be mainly a function of plant densities (Ball, Purcell, and Vories, 2000a,b; Poag, et al.; Popp, et al.; Wiley and Heath), the analysis focused on determining plant population density effects on yield to ultimately determine the effect of alternative seed survival rates for the different seed treatment, location, planting month and year scenarios.

Model Estimation

Two response functions were estimated to compare partial returns across different seeding locations, planting months, and soybean price scenarios. The first response function was used to estimate seed establishment or the rate of survival of a seed until four weeks past planting, (*ROS*) across the array of conditions in this study. In turn, this allowed estimation of the marginal cost of an established plant at four weeks past planting with the restrictive assumption that changes in seeding rate would not affect seedling survival (only one seeding rate, defined as seeds per row foot, was used in this study at each location and planting month combination although at varying row spacing). The second response function modeled the yield response to *PPD*. This was possible given the range of seedling emergence observed over the study conditions and hence allows the estimation of yield effects by changing the seeding rate and/or the seedling survival rate with seed treatment. The specification of these two equations was as follows:

(1) $ROS = f\,(SQ, TREAT, YR, PM, LOC)$

where $ROS = SC/SR$ was the stand count per 20-foot row observed at four weeks post planting (*SC*) divided by the number of seeds planted per 20-foot row (*SR*), *SQ* was a zero or one dummy variable for seed quality (1 = high quality seed, 0 = seed treated to lessen seed quality), *TREAT* was a set of ten zero or one dummy variables to compare the nine seed treatments to the control without seed treatment, *YR* were four zero or one dummy variables for experimental trial year, *PM* were three zero or one dummy variables for planting in April, May or June, and *LOC* were three zero or one dummy variables to adjust for differences in location. The model was estimated using restricted linear least squares with necessary coefficient restrictions across each group of dummy variables representing the treatment effects. The analysis was performed in EViews v. 2.0 (Greene; Maddala; Hall, et al.). All coefficients were calculated using White's heteroskedasticity-consistent estimators.

The yield response function was specified as follows:

(2) $Y = g\,(PPD, SQ, YR, TREAT, PM, LOC)$

where *Y* is the soybean yield achieved and *PPD* are plants per acre adjusted for row spacing differences across locations and years, with the remaining variables and baseline conditions as defined in Eq. 1. Non-linear responses were hypothesized for *PPD* and yield (Ball, Purcell, and Vories, 2000a,b; Duncan; Popp, et al.; Wiggans; Wiley and Heath). The quadratic and square root functional forms of the yield response function were tested using Ramsey's Reset test for misspecification bias also available in *Eviews* v 2.0 (Studenmund; Hall, et al.).

Economic Analysis

For each of the experimental conditions modeled in this study the estimated *ROS* was used to determine the seed and seed treatment cost per acre and to calculate *PPD* using a seed count of 3,000 seeds per pound. Using estimated *ROS* for the different study conditions, changing the seeding rate from 30, 45, and 60 pounds per acre, resulted in estimated *PPD*s that were then used in turn to estimate yields. Partial returns across seed treatments could then be calculated as yield × soybean price less seed and seed treatment costs on a per acre basis. Other crop production costs were the same regardless of seed treatment and hence not included in the analysis. Subsequently, varying the soybean price – from $4.50 to $13.50 per bushel – to reflect an array of market conditions allowed for sensitivity analysis on seed treatment recommendations.

Since a large number of alternatives were analyzed, partial returns across study conditions and seed treatment options were also compared using a minimum regret rule. So, in addition to reporting partial net returns for a strategy as well as their estimated averages across study conditions, the strategies were also individually compared to the optimal strategy for each location, planting month and year combination. The difference between a particular strategy's outcome compared to the optimal strategy for that location, planting month, and year was then averaged across all conditions to determine, on average, by how much a particular strategy would deviate from optimal partial returns. Hence the average regret is defined as the dollar loss per acre a producer would incur by choosing a non-optimal strategy across a set of particular location, year, and planting month combinations. This adds information to the analysis as reporting of average partial returns for each planting strategy alone does not involve a comparison across strategies. That is, a particular strategy could have highest average partial returns but be sub-optimal across a number of scenarios if it wins big for one particular strategy. The optimal strategy is the seed treatment choice with the least average regret or closest to zero as regret for a particular comparison is bounded by zero when the strategy is optimal. Now it could be that a particular strategy has a low average regret but significant variation in regret across strategy comparisons. For this reason the standard deviation of regret is also reported and, again, a lower number is desirable for consistent results. To summarize, analysis of average regret allows reporting of a large number of comparisons in one number.

Results

Model Estimation

The final estimates of the seed establishment equation (Eq. 1) are presented in Table 2. The model accounted for approximately 44 percent of the variation in the rate of survival over a wide range of environmental conditions and their interactions. All of the independent variables exhibited statistically significant responses either by themselves or as interactions. The signs on the coefficients were as expected (a reduction in survival rate with lower quality seed and improvements in survival rate with the seed treatment). Tables 3 and 4 highlight estimated survival rate (ROS) effects by seed treatment, location, year, seed quality, and planting month. *AM++* proved the most effective on both high and low quality seed to improve stand count.

The yield response function to PPD shown in Table 5 exhibited higher explanatory power compared to Eq. 1. Both linear and non-linear *PPD* effects showed statistically significant impacts on yield. However, only statistically significant impacts (at p-values less than 5% as indicated by at least one asterisk to the right of the t-statistic) were analyzed further. Further, statistically insignificant seed treatments, with absolute t-values less than one, were removed to reduce multicolinearity bias for remaining estimates. Highly significant coefficients on *PPD* in conjunction with expected signs supported a good model fit. While the Ramsey Reset statistic suggested some misspecification bias, the statistics for the square root functional form were superior to those of the quadratic functional form and similar to observations made by Popp, et al. The yield results obtained from using the regression coefficients were also in line with the actual yields observed in the experiment and were comparable to yields obtained in the study region for the treatment conditions observed.

Economic Analysis

Using coefficients from Tables 2 and 5, expected yields for each of the study conditions are presented in Tables 6 and 7 for high and low quality seed, respectively. This was done, so that a producer's decision to plant at a particular seeding rate could be simulated as the actual experimental results did have some variation in seeding rates with the changes in row spacing across locations dictated by experiment station equipment availability. The tables list estimated yields, partial returns and regret for the different locations by year, seed treatment and planting month using 45 pounds of seed/acre for both high and low quality seed. Averaging partial returns across study conditions by seed treatment alternative resulted in *AM++* showing the highest partial returns at $306 and $254 per acre for high and low quality seed, respectively. *AM++* was followed by *AL+* and *ST+* as most effective seed treatment alternatives to *AM++* for high and low quality seed, respectively. Analyzing the regret column for either high or low quality seed clearly indicated *AM++* to be the superior treatment. It was somewhat surprising, to find one seed treatment solution to be the answer consistently across all study conditions (one exception is the use of *AL+* at Keiser in April, 2004). It does suggest that a broad spectrum seed treatment with added insecticide is a profitable alternative to untreated seed as long as its cost is not prohibitive as in the case with *ST+*.

A comparison of use of low vs. high quality seed results at the targeted seeding rate of 45 pounds per acre also revealed that lower seedling survival rates as a result of low quality seed had a large negative impact on returns and yield, $52/acre and 7 bu/acre on average for the optimal seed treatment, respectively. Results not shown here suggested that doubling of the seeding rate would be required to maintain the average yield potential using the most profitable seed treatment. Even at these heightened seeding rates, partial returns are approximately $30/acre lower (compared to 45 lbs./acre of high quality seed) given the higher cost associated with doubling the seeding rate. Not included in this estimate is the impact of fewer acres seeded if no additional seed is purchased. As a result, producers are encouraged to: 1) ensure maintaining seed quality via proper storage; 2) raise seeding rates if seed quality appears compromised; and/or 3) only using high quality seed. These findings are similar to Poag, et al.'s study.

Table 8 summarizes the optimal choice under varying soybean price and seeding rate options, now only using high quality seed given the above results and additional observations in 2007 (when low-quality seed was not analyzed). Again, *AM++* outperformed the rest of the seed treatments with the exception of *AL+* at high seeding rates and low soybean prices. At the high seeding rates the seed treatment cost advantage of *AL+* ($0.01/lb) over *AM++* ($0.04/lb) outweighed the very modest decline in yield (0.4 bu/acre less than *AM++*) observed for *AL+* at that seeding rate. Beyond the high end of seeding rates shown in the Table (70 lbs. of seed), untreated seed also showed some promise although these estimates are likely outside the range of valid yield forecasts given the limited range in *PPD*s used to estimate the yield response to *PPD* in this study. At high seeding rates, the cost savings of no seed treatment are greater than the advantage of ensuring the survival of each seed as *PPD*s reach levels where yield no longer increases and hence untreated seed yields the same as treated seed. This situation could be relevant if lower-cost seed, such as on-farm conventional soybeans from the previous year, were used and the producer does not have access to seed treatment application equipment.

Final Comments

This study summarizes findings of soybean seed treatment studies conducted at Keiser, Stuttgart, and Hope, Arkansas under varying environmental conditions from 2004 to 2007. The conditions reported in these trials are expected to be representative of Arkansas soybean production. The reader is cautioned, however, that these results may not apply for other production regions or planting months, as significant variation was experienced even at the same location across planting months.

The study suggested that a producer, using high quality seed, could be advised to use a broad spectrum seed treatment with added insecticide. Further, at a 45 pound per acre seeding rate and ten year average soybean prices, as well as 2007 seed treatment costs, producer profitability could be enhanced by an average of $32 per acre using the optimal seed treatment when compared to using untreated seed. Noteworthy also was that untreated seed was never the optimal choice across all study conditions analyzed. Further, a single treatment was identified to be superior to two additional seed treatments with statistically significant yield responses across a range of soybean output prices and range of seeding rates. Finally, the analysis showed that use of low-quality seed is quite costly.

While these results are noteworthy, there are some limitations to the study. A broader set of seeding rates would likely have lead to better yield response function estimates. Only three of the nine treatments entered the model with statistically significant *PPD* impacts on yield. While likely cost prohibitive, a second level of seed per row foot would have enhanced the study results. Also, other than labeled recommendations for seed treatment may be more profitable, especially on expensive treatments like *ST+*. Finally, replication of the experiment across different soybean production methods such as no-till vs. conventional, bedded or drilled, or irrigated vs. dryland, would likely enhance the ability to generalize findings from this study to other production conditions.

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Table 1. Summary of data availability, 2007 to 2007, Hope, Stuttgart, and Keiser, Arkansas

Location	Year	Cultivar[a]	Planting Date	Yield Data	Seed Quality[b]	Stand Counts
Stuttgart	2004	Pioneer 94M90	4/29	Y	Hi	Y
			5/10	Y	Hi & Lo	Y
			6/15	Y	Hi & Lo	Y
	2005	Pioneer 94M90	na	Na	na	na
			5/12	Y	Hi & Lo	Y
			6/15	Y	Hi & Lo	Y
	2006	Pioneer 94M90	4/19	Y	Hi & Lo	Y
			5/19	Y	Hi & Lo	Y
			6/15	Y	Hi & Lo	Y
	2007	HBK4924	4/30	Y	Hi	Y
			5/24	Y	Hi	Y
			6/13	Y	Hi	Y
Keiser	2004	Pioneer 94M90	4/19	Y	Hi	Y
			5/21	Y	Hi & Lo	Y
			6/10	Y	Hi & Lo	Y
	2005	Pioneer 94M90	4/19	Y	Hi & Lo	Y
			5/12	Y	Hi & Lo	Y
			6/14	Y	Hi & Lo	Y
	2006	Pioneer 94M90	4/14	Y	Hi & Lo	Y
			5/19	Y	Hi & Lo	Y
			6/28	Y	Hi & Lo	Y
	2007	HBK4924	4/24	N	Hi	Y
			5/14	N	Hi	Y
			6/20	N	Hi	Y
Hope	2004	Pioneer 94M90	4/15	N	Hi	Y
			5/24	N	Hi & Lo	Y
			6/14	N	Hi & Lo	Y
	2005	Pioneer 94M90	4/21	Y	Hi & Lo	Y
			5/12	Y	Hi & Lo	Y
			6/8	Y	Hi & Lo	Y
	2006	Pioneer 94M90	4/14	Y	Hi & Lo	Y
			5/17	Y	Hi & Lo	Y
			6/15	Y	Hi & Lo	Y
	2007	HBK4924	4/23	N	Hi	Y
			5/15	N	Hi	Y
			6/13	N	Hi	Y

[a] Row spacing was 38" at Keiser (PPD of 68,779) and 32" at Stuttgart and Hope (PPD of 81,675) across all years and planting dates. 2007 Plantings in Hope used a 30" row spacing (PPD of 87,120).

[b] Seed was manually aged using Nanayakkara's (2001) procedure by exposing seed to 40^{o} C for 14 days at 12.9% moisture.

Table 2. Summary of restricted linear regression estimates of seedling survival rates as affected by seed quality, planting month, location, year, and seed treatment

Dependent Variable	*ROS*					
Independent Variables[a]	Coefficient Estimates		T-statistics	Independent Variables[a]	Coefficient Estimates		T-statistics
Constant	0.4707 **	182.05	*DAM++*	0.0626 **	9.46
DAPR	0.0126 **	5.84	*DMAX*	-0.0204 **	-3.08
DMAY	0.0063 **	3.14	*DVITA+*	-0.0212 **	-3.21
DJUN	-0.0189 **	-9.45	*DST*	0.0475 **	7.17
D04	0.0535 **	21.88	*DST+*	0.0624 **	9.39
D05	0.0109 **	4.48	*DSQ* × *DUNT*	0.2851 **	31.44
D06	-0.1171 **	-49.65	*DSQ* × *DAL*	0.2549 **	28.18
D07	0.0526 **	17.03	*DSQ* × *DAL+*	0.1849 **	20.45
DHOPE	0.0699 **	34.83	*DSQ* × *DAM*	0.1728 **	19.09
DSTUTT	-0.0626 **	-30.32	*DSQ* × *DAM+*	0.1529 **	16.91
DKEISER	-0.0072 **	-3.61	*DSQ* × *DAM++*	0.1721 **	19.02
DUNT	-0.1428 **	-21.50	*DSQ* × *DMAX*	0.2242 **	24.72
DAL	-0.0929 **	-14.04	*DSQ* × *DVITA+*	0.2177 **	24.04
DAL+	0.0187 **	2.82	*DSQ* × *DST*	0.1497 **	16.56
DAM	0.0297 **	4.49	*DSQ* × *DST+*	0.1569 **	17.30
DAM+	0.0565 **	8.54			
R^2 (%)	44.11				
Adj. R^2 (%)	43.52				
S.E. of regression	0.17				
# of observations	2,895				

[a] Independent variables included all treatment effects excluding seed quality (*DSQ*) which were added as interactions with the seed treatments and untreated control. While the seedling survival rate was a cardinal measurement of the ratio of plants at 4 weeks post planting to the number of seeds planted, all explanatory variables were zero-one dummy variables with *DAPR* – *DJUNE* reflecting the three planting months, *D04* – *D07* reflecting the different experiment years, *DHOPE* – *DKEISER* the three study locations in Arkansas, and *DUNT* – *DST+* reflecting the seed treatments as described in the text. All treatments were included in the model which required coefficients on planting month, planting year, seed treatment and seed treatment interactions individually to sum to zero to be able to estimate a constant term. Given the highly significant coefficient estimates on all independent variables, individual F-ratios on the restrictions are not reported.

Table 3. Estimated seed treatment effects by seed quality, seed treatment cost using commercially available label rates and expected treatment spectrum for common soil pathogens observed in Arkansas

		Seed Treatment Effects[a]								
		AL	*AL+*	*AM*	*AM+*	*AM++*	*MAX*	*VITA*	*ST*	*ST+*
		--- percentage improvement in seedling survival rate compared to untreated seed ---								
Initial Seed Quality	High	2.0%	6.1%	6.0%	6.7%	9.2%	6.1%	5.4%	5.5%	7.7%
	Low	5.0%	16.1%	17.3%	19.9%	20.5%	12.2%	12.2%	19.0%	20.5%
Treatment Cost	($/lb)	0.05	0.01	0.04	0.04	0.04	0.03	0.04	0.03	0.24
Targeted Treatment Spectrum		Pythium spp.	All	All	All	All & Insects	Rhizoctonia Solani & Fusarium spp.	Rhizoctonia Solani	All	All & Insects

[a] see seed treatment descriptions in the text.

Table 4. Estimated overall effects of planting time, location, and year effects on seedling survival rates

Percentage change in Seedling Survival Rate by Planting Month, Location and Year Effects Relative to May 2006 Stuttgart Base Line		
Planting Month	April	0.6%
	June	-2.5%
Location	Hope	13.2%
	Keiser	5.5%
Year	2004	17.1%
	2005	12.8%
	2007	17.0%

Table 5. Yield (Y) response to plant population linear regression results. Base scenario is May 2006 at Stuttgart, Arkansas

Dependent Variable	*Y*					
Independent Variables[a]	Coefficient Estimate	t-statistic	Independent Variables	Coefficient Estimate	t-statistic	
PPD	-0.0003	-2.28 *	$PPD^{0.5}$	0.24644	14.16 **	
PPD × *DSQ*	-0.0002	-6.81 **	$PPD^{0.5}$ × *DSQ*	0.07181	7.10 **	
PPD × *D04*	-0.0004	-4.13 **	$PPD^{0.5}$ × *D04*	0.17856	4.09 **	
PPD × *D05*	-0.0004	-4.78 **	$PPD^{0.5}$ × *D05*	0.28943	6.18 **	
PPD × *D07*	0.0009	4.56 **	$PPD^{0.5}$ × *D07*	-0.50887	-4.64 **	
PPD × *DAPR*	-0.0002	-2.03 *	$PPD^{0.5}$ × *DAPR*	0.13276	2.10 *	
PPD × *DJUN*	0.0005	8.92 **	$PPD^{0.5}$ × *DJUN*	-0.28257	-9.52 **	
PPD × *DAL+*	-0.0001	-2.12 *	$PPD^{0.5}$ × *DAL+*	0.03415	2.34 *	
PPD × *DAM*	-0.0001	-1.63	$PPD^{0.5}$ × *DAM*	0.02250	1.63	
PPD × *DAM+*	-0.0001	-1.41	$PPD^{0.5}$ × *DAM+*	0.02352	1.45	
PPD × *DAM++*	-0.0001	-2.34 *	$PPD^{0.5}$ × *DAM++*	0.04459	2.51 **	
PPD × *DST*	-0.0001	-1.64	$PPD^{0.5}$ × *DST*	0.02338	1.66	
PPD × *DST+*	-0.0001	-3.18 **	$PPD^{0.5}$ × *DST+*	0.04509	3.27 **	
PPD × *DKEISER*	-0.0003	4.59 **	$PPD^{0.5}$ × *DKEISER*	0.14454	4.66 **	
PPD × *DHOPE*	0.0004	3.81 **	$PPD^{0.5}$ × *DHOPE*	-0.31614	-5.20 **	
D04	-18.9877	-3.76 **				
D05	-43.3430	-7.33 **				
D07	78.8465	5.14 **				
DAPR	-22.6421	-2.79 **				
DJUN	20.0624	5.81 **				
DKEISER	-10.4320	-3.07 **				
DHOPE	41.0065	5.21 **				
R^2 (%)		63.80				
Adj. R^2 (%)		63.23				
S.E. of regression		9.61				
F-statistic		67.79 **				
# of observations		1,290				

[a] Independent variables included *PPD* (plant population density), year dummy variables (*D04..D07*), planting month dummy variables for April (*DAPR*) and June (*DJUNE*) yield effects relative to May, location dummy variables for Keiser (*DKEISER*) and Hope (*DHOPE*) effects relative to Stuttgart as well as one way interactions of *PPD* with year, planting month, seed treatment (*DAL+, DAM, DAM+, DAM++, DST, DST+*), location and seed quality (*DSQ*). Effects with absolute t-statistic values less than 1 were excluded from the model to reduce multicollinearity. * and ** indicate statistical significance levels of 5 and 1%, respectively.

Table 6. Estimated yield, partial returns[a] and regret[b] by seed treatment using 45 pounds of high quality seed per acre and the 10-year average soybean price of $7.96 in 2007. Treatment combinations without experimental yield data and insignificant yield responses were excluded.

Location, Year and Month			Yield (bu/acre)				Partial returns ($/acre)				Regret ($/acre)			
			Unt	AL+	AM++	ST+	Unt	AL+	AM++	ST+	Unt	AL+	AM++	ST+
Stuttgart	2004	April	43	44	45	44	306	316	320	304	14	4	0	16
		May	47	49	49	48	341	353	358	341	16	4	0	17
		June	31	33	34	33	209	229	234	217	25	6	0	18
	2005	May	33	51	53	51	229	375	384	365	155	9	0	18
		June	41	59	61	59	296	435	447	428	151	12	0	19
	2006	April	37	41	42	41	261	290	300	283	39	10	0	17
		May	41	45	47	46	296	325	334	318	38	10	0	17
		June	24	28	30	29	161	189	199	183	38	10	0	17
	2007	April	47	50	51	49	343	360	368	349	25	7	0	19
		May	52	54	55	54	377	396	404	385	27	8	0	19
		June	35	38	39	38	244	267	277	258	33	11	0	20
Keiser	2004	April	49	49	49	48	352	354	352	337	1	0	2	17
		May	53	54	54	53	389	393	392	377	4	0	0	16
		June	37	39	39	38	263	274	277	260	14	4	0	17
	2005	April	51	53	54	53	375	389	393	376	18	4	0	17
		May	56	58	59	57	410	426	431	413	21	5	0	17
		June	39	42	43	42	276	299	307	288	31	8	0	19
	2006	April	45	48	49	48	325	348	355	338	29	7	0	16
		May	49	52	53	52	360	382	390	373	30	7	0	16
		June	32	36	37	36	224	249	257	241	33	9	0	17
Hope	2005	April	32	32	33	32	218	224	226	208	8	2	0	17
		May	36	37	38	37	255	263	267	249	11	3	0	18
		June	20	22	24	22	129	145	152	132	23	7	0	19
	2006	April	27	28	29	28	179	189	192	176	13	3	0	16
		May	31	33	33	32	214	225	229	213	15	4	0	16
		June	15	16	17	16	82	97	103	86	21	6	0	17
		Average	39	42	43	42	274	300	306	288	32	6	0	17
		Std. Dev.	11	11	11	11	84	89	89	89	37	3	0	1

[a] Partial returns are calculated as yield × price less seed and seed treatment costs.

[b] Regret is the dollar loss per acre a producer would incur by making a non-optimal treatment choice. For the first planting month, year, location and seed treatment alternatives the choice of *AM++* is optimal as it has the highest partial return and yield and, therefore, zero regret, whereas use of *ST+* resulted in the highest regret given the higher cost of treated seed and lesser yield advantage to untreated seed than the optimal choice.

Table 7. Estimated yield, partial returns[a] and regret[b] by seed treatment using 45[c] pounds[c] of low quality seed per acre and the 10-year soybean price of $7.96 in 2007. Treatment combinations without experimental yield data and insignificant yield responses were excluded.

Location, Year and Month			Yield (bu/acre)				Partial returns ($/acre)				Regret ($/acre)			
			Unt	AL+	AM++	ST+	Unt	AL+	AM++	ST+	Unt	AL+	AM++	ST+
Stuttgart	2004	May	35	44	46	45	244	316	328	312	84	11	0	15
		June	19	27	28	28	116	179	191	176	75	12	0	15
	2005	May	27	41	45	44	184	295	319	304	135	24	0	15
		June	36	48	51	50	250	348	372	357	121	24	0	14
	2006	April	15	30	33	32	89	202	226	213	137	24	0	13
		May	23	35	38	37	151	244	264	251	113	21	0	13
		June	14	19	21	21	75	119	134	121	59	15	0	13
Keiser	2004	May	44	51	53	52	319	375	386	370	67	10	0	16
		June	27	34	36	35	184	240	252	237	68	13	0	16
	2005	April	34	47	49	48	236	337	356	341	121	19	0	15
		May	39	51	53	53	273	370	390	374	116	19	0	15
		June	21	33	36	35	137	229	250	235	113	21	0	15
	2006	April	26	39	42	41	169	277	298	284	129	21	0	14
		May	32	44	46	46	221	315	334	320	113	19	0	14
		June	19	27	29	29	118	182	199	185	80	16	0	13
Hope	2005	April	23	30	31	30	152	202	213	197	62	11	0	16
		May	28	34	36	35	188	236	248	232	60	12	0	16
		June	11	17	19	18	53	101	115	99	62	14	0	16
	2006	April	21	25	26	25	130	163	171	156	41	9	0	15
		May	26	29	30	30	176	199	206	192	30	8	0	15
		June	13	13	14	13	67	68	74	60	7	6	0	14
		Average	25	34	36	36	168	238	254	239	85	16	0	15
		Std. Dev.	9	11	11	11	71	88	90	90	37	6	0	1

a Partial returns are calculated as yield × price less seed and seed treatment costs.

b Regret is the dollar loss per acre a producer would incur by making a non-optimal treatment choice. For the first planting month, year, location and seed treatment alternative (top row) the choice of *AM++* is optimal as it has the highest partial return and yield and, therefore, zero regret. By comparison, in June, 2006, at Hope, the use of *ST+* resulted in the highest regret given the higher cost of treated seed and no yield advantage to untreated seed than the optimal choice.

c Approximately double the seeding rate is required to maintain the yield potential given the lower rates of survival of low quality seed. Doubling the seeding rate would half the number of acres planted without purchasing additional seed and also double the seed cost. Further analyses are available from the author upon request.

Table 8. Optimal choice of seed treatment selected on the basis of minimum average regret[a] and partial returns across planting month, year, and location options using high quality seed. Treatment combinations without experimental yield data and insignificant yield responses were excluded.

Optimal Seed Treatment **Avg. Partial Returns ($/acre)** Avg. Regret ($/acre)		**Soybean Price Scenario** Low (4.50)	 Avg. (7.96)	 High (13.50)
Seeding Rate (lbs/acre)	Low (30)	*AM++* **160** 0	*AM++* **301** 0	*AM++* **528** 0
	Avg. (45)	*AM++* **157** 0.09	*AM++* **306** 0.07	*AM++* **543** 0.06
	High (60)	*AL+*[b] **144** 4.10	*AM++* **290** 6.88	*AM++* **525** 10.92

[a] Regret is the dollar loss per acre a producer would incur by making a non-optimal treatment choice for a particular situation (planting month, location and seed treatment) and hence regret values close to zero represent an optimal strategy. The average regret is calculated across all study conditions for which yield data were available. An average close to zero suggests that the seed treatment was optimal across most situations observed in the study.

[b] Note that *AM++* was second best with average partial returns of $143 and average regret of $4.39.